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Meso-Scale Metrology Tools: A Survey of Relevant Tools and a Discussion of Their Strengths and Weaknesses

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Meso-Scale Metrology Tools: A Survey of Relevant Tools and a Discussion of Their Strengths and Weaknesses

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Abstract
Lawrence Livermore National Laboratory, LLNL, manufactures laser experiment targets made of cylindrical and spherical components and assemblies that are generally 2 mm in size or smaller, which are machined with micron level accuracy. The targets illustrated in Figure 1 exhibit many features that are common to typical inertial confinement fusion, ICF, and high energy density laser targets. The left side of Figure 1 illustrates a cylindrical target composed of multiple materials of various shapes, including a disk that has a multi-mode sinusoid with a 4 μm amplitude cut into it. The spherical target on the right consists of an inner capsule surrounded by four concentric hemispheres made of foams and polystyrene that are bonded together at a butt joint. Targets such as these are currently being manufactured for laser experiments conducted on the Omega Laser at the University of Rochester, and they are beginning to be fabricated for the National Ignition Facility[i],[ii], NIF. The targets need to be fully characterized with an uncertainty of +/- 1 μm, but in approximately five years, the required accuracy is expected to become +/- 0.25 μm. It is difficult to find metrology tools than can adequately measure these laser targets.

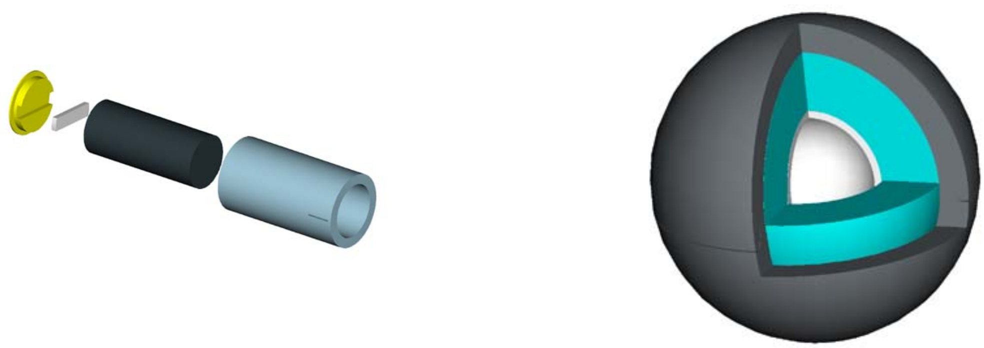

Figure 1. Two typical laser target geometries

The requirements for a laser experiment revolve around matching experimental laser shot results with results from predictive physics codes. The ability to provide a complete set of accurate dimensional metrology on a target is the input to the physics model. Therefore any inaccuracy or lack of data, affects the accuracy of the predictive model. In fact, it is more critical to have accurate metrology data rather than accurate manufacturing in this case. Diagnostics of the experimental results and the ability to resolve the physical behavior of the effect being modeled is the other element of the experiment cycle that is critical. Any of these errors reduces the ability to match the experimental and theoretical findings. One of the tasks of LLNL's target fabrication group is to address metrology capabilities at the meso-scale, several of which are described in the current paper.

Metrology plays a key role in fabrication and quality control on these meso-scale laser targets. Modern CNC machining equipment can provide positional resolution on the order of tens of nanometers over lengths of several millimeters. As the target fabrication group currently has no metrology tools that can adequately measure parts on these scales, we believe that we are able to manufacture components with less uncertainty than we can measure them. Therefore, there is a critical shortcoming in dimensional metrology of these fabricated components, and new metrology tools are needed for process control and verification in meso-scale manufacturing. This paper provides a summary of current metrology capabilities at small scales and reveals a need for additional tools at the micro/meso-scale.

A survey of the capabilities of various metrology tools has been started to identify areas where metrology tools are commercially available and where tools need development. Figure 2 provides a qualitative view identifying areas where tools exist and the general capabilities for each tool category. It also identifies an area where tools may need development. LLNL would like to address a broad community knowledge base to contribute to this meso-scale metrology area and to identify other tools that are applicable in this realm. The graph focuses on commercially available tools, even though a few one-off tools are known to exist, such as the Phillips CM, and the NPL "small CMM." It would be desirable to include these types of tools on a separate graph.

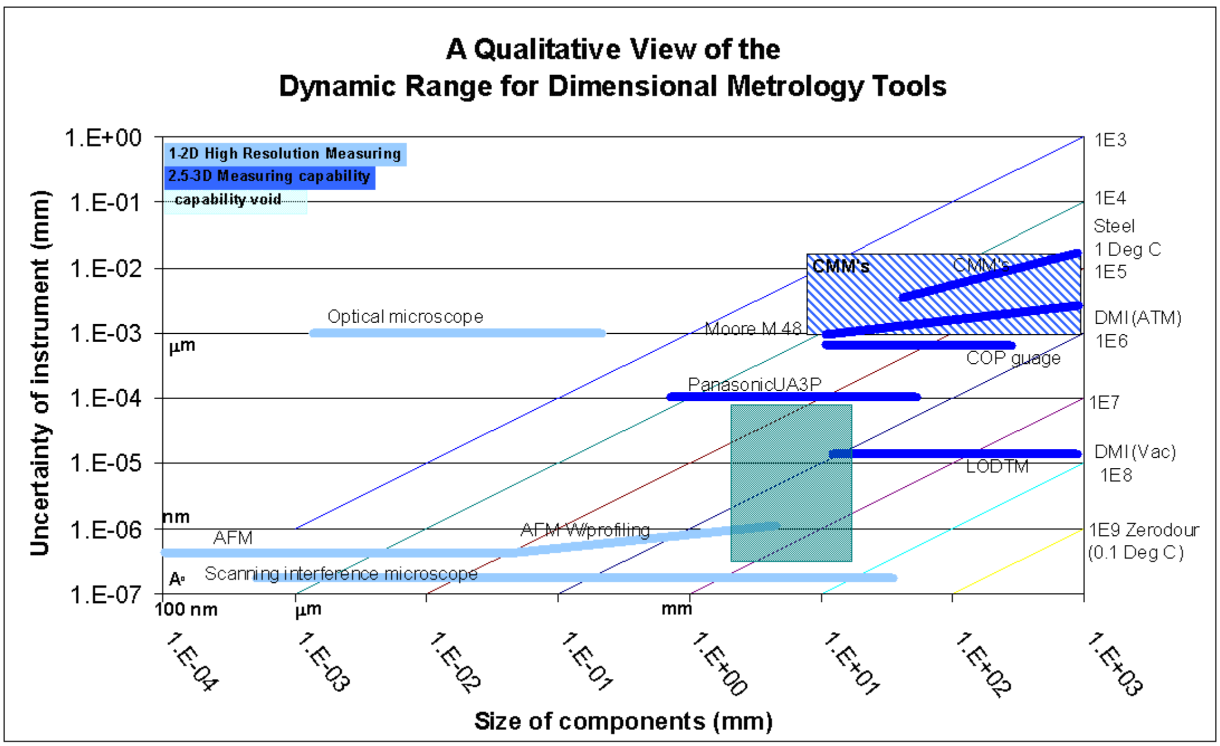

Figure 2. A qualitative view of the dynamic range of metrology tools.

The graph shows uncertainty of measurement versus dynamic range for various metrology tools. This type of graph is commonly used to illustrate the capabilities of precision manufacturing processes and tools. These are plotted against lines of specific accuracy (µm/M) for standard materials and measurement techniques. For example, steel would grow 1 µm/M per degree Celsius. This graph represents a qualitative look at the range and uncertainty of a broad range of metrology tools. Many of the identified tools have capabilities in 1 and 2 dimensions, and a few claim to have 3-D capabilities, but these are really only 2.5-D devices. Some LLNL metrology tools have been included for a historical perspective.

Figure 2 illustrates a gap in metrology capabilities for the scales relevant to target fabrication. This gap falls in the meso-scale, where components range in size from tens of microns to millimeters, and accuracies range from nanometers to tenths of a micron. The current paper is intended to serve as a basis for formulating a plan for developing needed meso-scale metrology tools for target fabrication and other meso-scale applications. There is an apparent shortcoming in meso-scale metrology tools and a national need for developing them, and discussions should be initiated with interested parties and experts in the field to pursue this area of metrology development.

Table 1. The Data set and notes on the various metrology devices.

	Measuring Instruments	Primary axis uncertainty - (meters)	Uncertainty in other 2 dimen. 2D	# meas dim	Min probe size mm	Feature size (M)	Min Range (M)	Max Range (M)	Notes
A	**AFM w/o profiling**	1.00E-10	??	2.5D	Non Con	5.00E-10	1.00E-10	3.00E-05	5 um Z limit on feature size. Time consuming
B	**AFM w/Profiling stage**	1.00E-09	1.00E-08	2.5D	Non Con	5.00E-09	1.00E-10	1.00E-02	Have to stitch together many small data sets
C	**Panasonic UA3P**	1.00E-07	1.00E-07	2.5D	4.00E-03	5.00E-06	0.00001	0.05	Acc. 0.1 um under 30deg dec. to .3 um @ 60 deg off vertical
D	**Optical Microscope**	1.00E-06	1e-6&1e-5?	2D	Non Con	2.00E-06	2.00E-06	5.00E-05	User views edges and estimates boundaries
E	**"Best CMM" Moore/Leitz**	1.00E-06	1.00E-06	3D	5.00E-01	??	0.0001	0.001	1 um over larger ranges?
		5.00E-06	5.00E-06				0.001	1	
F	**Small Inexpensive CMM**	5.00E-06	5.00E-06	3D	5.00E-01	1.00E-03	0.001	0.001	Under 50K$ CMM's
		1.20E-05	1.20E-05				0.001	0.4	
G	**Small Radius Gauge**	3.00E-07	5.00E-07	2D	0.5	0.002	0.0005	50	Spherical or cylindrical inner & outer contour
H	**COP/Prism**	1.00E-06		3D	5.00E-01		0.1	0.5	Prefers surfaces of revolution
I	**Taylor Hobson**	1 Ra	na	1D			0.004	0.12	Surface and profile
j	**Interference microscope**	2.50E-08	2.50E-08	2.5D	Non Con	5.00E-07	5.00E-07	5.00E-04	
k	**Scanning interference microscopes**	1.00E-10	5.00E-07	2.5D	Non Con	5.00E-07	5.00E-07	0.15	"3D" surface Profiling. Limited by lope of surface 17deg?
l	**Somergren interferometer**	1.00E-10		2.5D	Non Con	0.001	0.001	1	
m	**LODTM**	2.50E-08	2.50E-08	2.5D	0.5	0.001	0.001	1.5	2 Axis lathe - x, z, θ coordiantes??

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[i] "High Energy-Density Science on the National Ignition Facility", Campbell E. M., Cauble R., Remington B. A. UCRL-ID-129009, 1997.
[ii] "Conceptual Design of the National Ignition Facility", Paisner J., et al., UCRL-JC-117365

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